162

Reprinted from AGRONOMY JOURNAL
Vol. 63, Sept.-Oct. 1971, p. 669-674

Interpreting the Rate of Change in Nitrate-Nitrogen in Sugarbeet Petioles[1]

J. N. Carter, M. E. Jensen, and S. M. Bosma[2]

ABSTRACT

Nitrate-nitrogen in sugarbeet petioles is used to evaluate current N status of sugarbeet crops. Since the NO_3-N changes rapidly during the season, better relationships are needed to interpret these data relative to sugarbeet N nutrition.

Sugarbeets (*Beta vulgaris,* L.) were grown at four N fertilization rates and two irrigation levels to determine the root yield, sucrose percentage, sucrose yield, and N uptake in relation to the NO_3-N concentration in the petioles. NO_3-N in beet petioles increased to a peak concentration and then decreased exponentially during the two growing seasons on all treatments. The exponential decrease after the peak enables prediction of the NO_3-N in the petioles during the remainder of the growing season. This rate of change approach can be used to predict N needs when adding supplemental N for sugarbeets and to characterize the N status of soil-crop systems.

Additional index words: **Petiole analysis, Nitrogen uptake.**

THE nitrate-nitrogen content of sugarbeet petioles is an excellent indicator of the nitrogen nutrition status of sugarbeets (*Beta vulgaris,* L.). Previous investigators have primarily related a minimum value of NO_3-N status during the season to sucrose production. For example, Ulrich suggested that the critical low range for NO_3-N, based on water-extractable nitrate from petioles, is 1000 ppm (6, 7), and that concentrations below the critical level for any appreciable time before midseason may result in lower root and sucrose yield. Experience in the Twin Falls, Idaho, area indicates that petiole NO_3-N should be approximately 1000 ppm and that the available N supply of the soil should be nearly depleted about 4 to 6 weeks before harvest, or about Aug. 20, to maximize yield, sucrose percentage, and purity.

The rate of change in petiole NO_3-N reflects the net effect of rate of uptake and rate of assimilation of N. The rate of change between two sampling periods after petiole NO_3-N begins to decrease has the potential of providing not only additional information on the current N nutritional status of sugarbeets, but also enables the prediction of the probable status during the balance of the growing season. Predicting petiole NO_3-N concentration 4 to 6 weeks before harvest, for example, from petiole analyses earlier in the season, would enable the producer to apply additional N fertilizer, if needed, to maximize yield and sucrose production. This paper summarizes procedures that can be used to predict the NO_3-N concentration in sugarbeet petioles during the balance of the season based on samples taken during two midseason sampling periods.

PROCEDURE

Experiments conducted in 1966 and 1967 on a Portneuf silt loam near Twin Falls, Idaho, and the results of studies conducted in other areas in the western United States were utilized to illustrate the typical pattern in the change in NO_3-N in the petioles as the season progresses. The 1966 experimental site had been cropped to barley without fertilizer in 1965, and the 1967 site had received 112 kg of N/ha and was cropped to beans in 1966.

Four replications involving two irrigation levels as main plots and four N fertilizer rates as subplots were used. Ammonium nitrate at the rates of 56, 112, 168, and 224 kg N/ha was applied as a side-dressing just below and to the side of the irrigation furrows to minimize leaching (June 17, 1966 and June 20, 1967). The sugarbeets were planted in 60-cm rows (April 23, 1966 and April 8, 1967), and were thinned to a spacing of approximately 23 cm within rows.

Irrigation water was applied to alternate furrows at each irrigation. Two irrigation levels were used. During 1966 the M_1 treatment was irrigated for 12 hours when the soil moisture tension at the 40-cm depth approached 0.65 atm, except for the first and second irrigations. The first irrigation of 6 hours was made when the tension reached 0.45 atm, and the second of 8 hours at 0.55-atm tension. The M_2 treatment was irrigated at the same time as the M_1, except that the duration of the first irrigation was 12 hours and that of all others was 24 hours. The M_1 treatment received 72 cm, and the M_2 received 114 cm of irrigation water during the 1966 growing season (Table 1). Similar amounts of water were applied to the beets during the 1967 season. The M_1 irrigation treatment was considered adequate, and the M_2 treatment, excessive based on other experiments conducted in 1964 and 1965.

Root and top samples were taken at weekly intervals from 3-m row lengths on all replications of the M_1-112 kg N/ha treatment to determine N uptake for the 1967 season. Sufficient plot area was provided so that these samplings did not influence final yield measurements. The plant samples were washed, weighed, cut into small sections, and dried at 65 C. The dry

[1] Contribution from the Northwest Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA; Idaho Agricultural Experiment Station cooperating. Received August 5, 1969.

[2] Research Soil Scientist, Research Agricultural Engineer, and Physical Science Technician, respectively, Snake River Conservation Research Center, Kimberly, Idaho 83341.

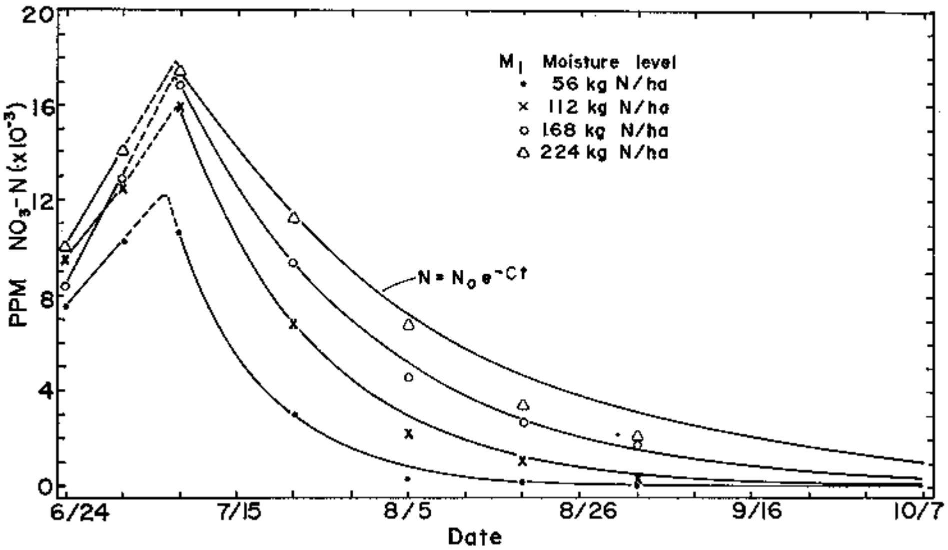

Fig. 1. NO_3-N concentration in sugarbeet petioles at various sampling dates during 1966 on the M_1 moisture level at four rates of applied N.

Table 1. Summary of irrigations.

Date 1966	Water applied* M_1	Water applied* M_2	Date 1967	Water applied† M_1	Water applied† M_2
	cm			cm	
4/25	6.4	6.4	5/26	7.1	12.7
5/25	4.6	6.6	6/27	10.2‡	15.2‡
6/28	8.1‡	8.1‡	7/11	7.1	12.7
7/15	6.6	10.2	7/21	7.1	12.7
7/27	7.1	10.7	8/1	7.1	12.3
8/5	7.6	13.2	8/10	7.1	12.7
8/17	6.6	11.7	8/22	7.6	13.7
8/31	7.1	13.5	8/31	6.9	11.6
9/14	8.6	16.8	9/14	7.1	12.3
9/29	9.1	16.5	9/29	7.1	7.1

* Measured. † Estimated from hours of irrigation and intake rate of soil. ‡ Every furrow irrigated.

weight was determined and the plant samples were ground to pass a 420-micron sieve. Total N in these samples was determined by the Kjeldahl procedure modified to include nitrate (2).

Petiole samples were taken at 1- or 2-week intervals during the 1966 season, and at weekly intervals during the 1967 season. These consisted of 40 of the youngest fully mature petioles taken at random from each plot at each sampling date. The petioles were cut in half. Twenty leaf ends and 20 beet ends of these petioles, randomly selected, were used for a quick-test for NO_3-N content using fresh tissue. The remaining halves were cut into 0.5-cm sections, freeze-dried, ground to pass a 420-micron sieve, and subsampled for NO_3-N analysis.

The NO_3-N concentration of the freeze-dried samples was determined by the phenoldisulfonic acid method (5) using a water extract of the beet petioles. The quick-tests on the fresh tissue were made by a commercial fertilizer company using a modified method (3).

Standard cultural and harvesting procedures were used. The beet roots were harvested in October during both years (Oct. 17, 1966 and Oct. 10, 1967). Random selection of beet roots was made during harvest for sucrose analysis. Sucrose analysis was done by the Amalgamated Sugar Company using their standard procedures.

RESULTS AND DISCUSSION

During the 1966 season the NO_3-N concentration on the 56-kg N/ha treatment dropped below 1000 ppm early in August (Fig. 1, 2), and the root yield was about 5 metric tons/ha less than on the higher N treatments (Table 2). Sucrose percentage in the roots was reduced slightly at the highest level of applied N, which offset the increase in root yield. Therefore, the sucrose production was about the same on all but the low N treatments. There were no significant yield differences between irrigation treatments.

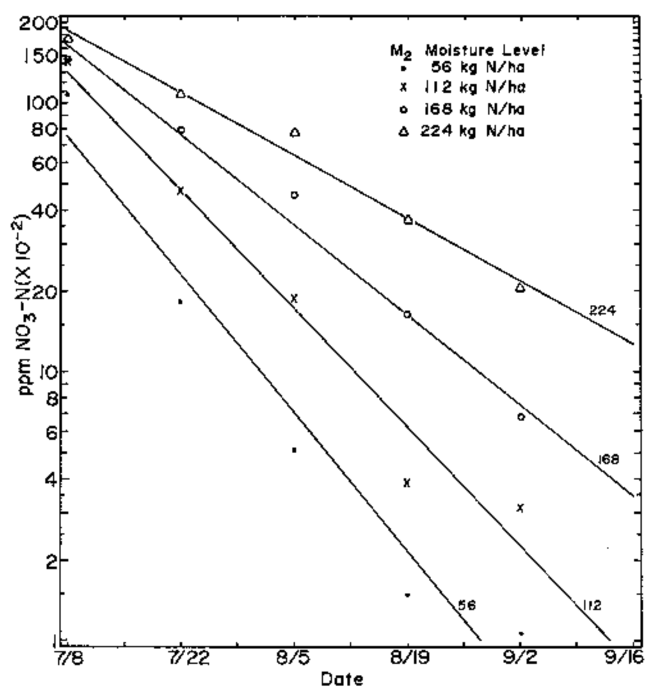

Fig. 2. NO_3-N concentration in sugarbeet petioles at various sampling dates during 1966 on the M_2 moisture level at four rates of applied N.

During the 1967 season the NO_3-N in the beet petioles did not drop below 2,000 ppm at any time during the sampling period (Fig. 3, 4), but was less than 3,000 ppm by mid August on the M_2-56 N treatment (Fig. 4). Root yield was 3 to 4 metric tons less on this treatment as compared to the other N treatments, indicating that the critical NO_3-N level may be dependent on the growth conditions (Table 2). The NO_3-N concentration was high on all treatments,

Table 2. Effect of N and moisture level on root yield, sucrose yield, and sucrose percentage of beet roots.

	1966						1967					
	M_1			M_2			M_1			M_2		
	Root	Sucrose		Root	Sucrose		Root	Sucrose		Root	Sucrose	
N applied, kg/ha	yield, T/ha	Yield, T/ha	%	yield, T/ha	Yield, T/ha	%	yield, T/ha	Yield, T/ha	%	yield, T/ha	Yield, T/ha	%
56	50.4	8.69	17.3	54.4	9.43	17.3	56.9	8.49	15.0	49.3	7.32	14.9
112	57.1	9.92	17.4	54.2	9.34	17.2	55.3	8.15	14.7	52.4	7.71	14.7
168	55.1	9.50	17.3	57.6	9.79	17.0	52.6	7.50	14.3	53.1	7.48	14.1
224	55.8	9.45	16.9	59.6	9.86	16.6	53.5	7.57	14.1	53.3	7.73	14.5

† Average area root yield, T/ha: 1966 = 44.8; 1967 = 47.7
Average area sucrose %: 1966 = 16.5; 1967 = 15.7

Analysis of variance

		Mean squares					
		1966			1967		
		Root	Sucrose		Root	Sucrose	
Component	df	yield	Yield	%	yield	Yield	%
Replication	3	5.5	0.37	0.48*	50.2	1.89	0.40
Moisture (M)	1	29.2	0.39	0.26	53.4	1.14	0.01
Error (a)	3	66.0	1.72	0.03	32.5	0.96	0.19
Fertilizer (F)	3	40.1*	0.69	0.57	1.7	0.35	0.99
M × F	3	22.3	0.64	0.06	26.2**	0.67*	0.10
Error (b)	18	10.0	0.34	0.30	4.0	0.14	0.35
Total	31						

* Significant at the 5% level. ** Significant at the 1% level.

but varied with N application rates. The sucrose percentage in the roots on the M_1 moisture treatment decreased slightly with higher N application rates. Since no general yield increases were caused by N application rates, sucrose yields were reduced.

In practically all treatments sampled, the NO_3-N concentration in the petioles increased to a peak value early in the growing season and then decreased rapidly (Fig. 1, 4). The rate of decrease in NO_3-N was small toward the end of the growing season. The peak concentration is attributed to the high available soil and fertilizer N and a low rate of N use by the plant during early growth stages. The exponential decrease in the NO_3-N concentration in petioles that follows was linearly related to the proportion of N uptake, N_t/N_T, where N_t is the N uptake at any time during the season, and N_T is the total N uptake for the entire season (Fig. 5).

Analyses of these data indicate that after the NO_3-N concentration in sugarbeet petioles reached a peak on all treatments, the decline in concentration fol-

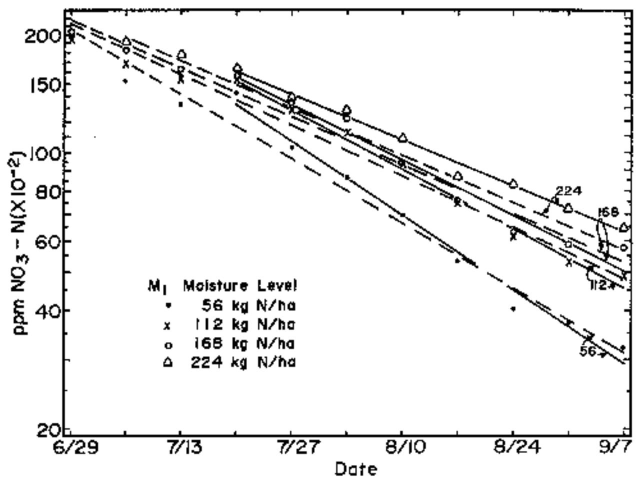

Fig. 3. NO_3-N concentration in sugarbeet petioles at various sampling dates during 1967 on the M_1 moisture level at four rates of applied N.

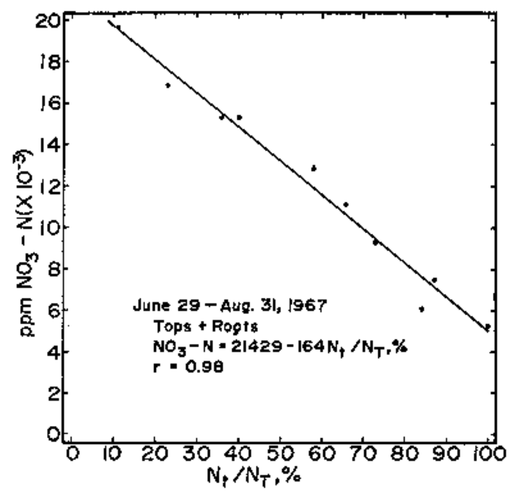

Fig. 5. Concentration of NO_3-N in beet petioles in relation to the N uptake by the plant.

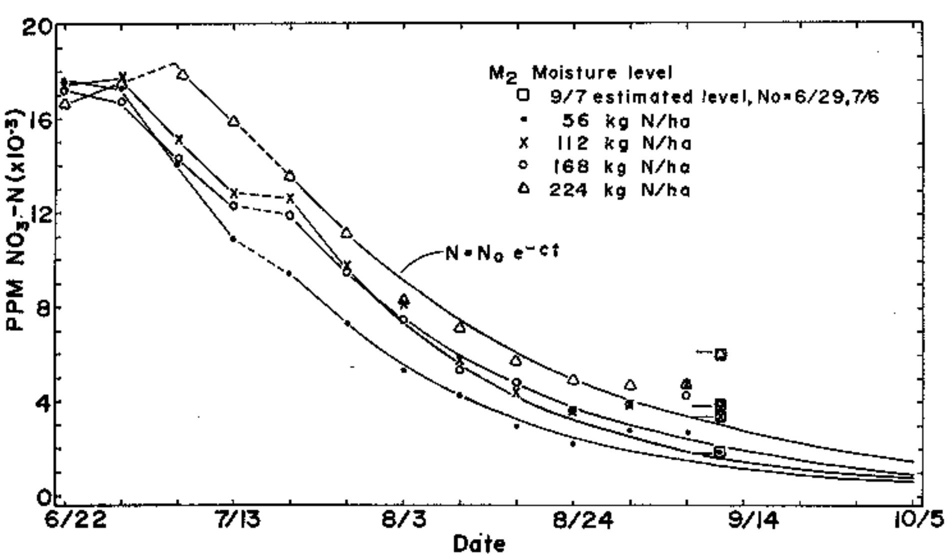

Fig. 4. NO_3-N concentration in sugarbeet petioles at various sampling dates during 1967 on the M_2 moisture level at four rates of applied N.

lowed a definite functional relationship. The rate of decrease in NO_3-N in the petioles was proportional to the concentration in the petioles as indicated by equation [1]:

$$dN/dt = -CN \qquad [1]$$

where N is the NO_3-N concentration in the petioles, t is time, and C is a constant for a given treatment. Integration of equation [1] with the concentration of NO_3-N at $t = 0$ used as the integration constant results in the following equation:

$$N = N_0 \exp(-Ct) \qquad [2]$$

where N is the NO_3-N concentration at time t, N_0 is the concentration at the first sampling date after the peak occurs, t is any time after the first sampling date ($t = 0$), and C is a constant for any given treatment or beet field.

The constant C can be evaluated by determining the NO_3-N concentration at two dates any time after the peak occurs using the following equations:

$$C = (\ln N_0 - \ln N)/t \qquad [3a]$$

$$C = (2.3/t)(\log_{10} N_0 - \log_{10} N) \qquad [3b]$$

where N_0 is the concentration at the first sampling date, N is the measured NO_3-N concentration at time t. C can be determined graphically by plotting on semi-logarithmic paper (Fig. 2, 3), and if the points 10,000 and 1,000 ppm are used, then

$$C = 2.3/\Delta t \qquad [4]$$

where Δt equals the days for NO_3-N concentration in the petioles to go from 10,000 to 1,000 ppm. The number of days required for N to decrease from N_0 until $N = 0.3678N_0$ is 1/C.

Since the reciprocal of the constant C (Table 3) is the time required for petiole NO_3-N to decrease to $0.3678N_0$, 1/C values represent the N fertility status of a given soil-crop system (rate of supply relative to rate of use), and may be extremely useful in comparing different systems since it remains relatively constant over a period of several weeks.

The time required for NO_3-N to decrease to 1000 can be calculated as follows:

$$t' = \ln(N_0/1000) \times (1/C) \qquad [5]$$

where t' is the number of days required for N to decrease from N_0 to 1000 ppm (Table 3).

Equation [2] was evaluated in Fig. 1 and 2 for the 1966 season, in Fig. 3 and 4 for the 1967 season, and regression analyses for both years are summarized

Table 3. Effect of N and moisture level on the reciprocal of the C values and the time required for NO_3-N to reach 1000 ppm.

N applied	1966		1967			
	M_1†	M_2†	M_1	M_2	M_1¶	M_2¶
kg/ha			1/C*			
56	10	12	37‡	33‡	32	36
112	13	14	48‡	42‡	40	42
168	25	18	50‡	43‡	44	43
224	26	26	56§	41§	52	43
			Days to 1,000 ppm NO_3-N			
56	24	24	113‡	92‡	83	75
112	38	35	145‡	121†	110	100
168	68	51	153‡	122‡	120	100
224	76	76	167§	119§	145	108

* 1/C = days for petiole NO_3-N to decrease from N_0 to 0.3678 N_0. † N_0 on 7/8. ‡ N_0 on 6/29. § N_0 on 7/6. ¶ N_0 on 7/20.

Table 4. Results of regression analysis to evaluate the predictive value of equation [2].

Treatment, kg N/ha	M_1			M_2		
	N_0*	C	r^2	N_0*	C	r^2
		1966 (7/8-9/2)				
56	10,156	0.098	0.98	7,429	0.084	0.96
112	18,575	0.076	0.98	13,098	0.073	0.97
168	16,146	0.041	0.99	16,878	0.055	0.99
224	18,553	0.038	0.99	18,760	0.038	0.98
		1967 (6/29, 7/6-9/7)				
56	20,646	0.027	0.98	16,407	0.030	0.94
112	21,293	0.021	0.98	18,011	0.024	0.92
168	21,909	0.020	0.97	16,843	0.023	0.94
224	19,904	0.018	0.99	17,710	0.024	0.97
		1967 (7/20-9/7)				
56	13,388	0.031	0.99	8,086	0.028	0.85
112	15,355	0.025	0.99	10,809	0.024	0.81
168	15,542	0.023	0.96	10,373	0.023	0.86
224	16,070	0.019	0.98	12,232	0.023	0.93
		Other locations				
California†	4,476	0.054	0.98			
Montana‡	3,042	0.032	0.77			
Utah§	9,093	0.029	0.95	8,435	0.037	0.98
Idaho 0 N	12,498	0.059	0.93	8,161	0.059	0.88
134 N	18,160	0.032	0.94			

* Determined as the constant in the regression equation, $t = 0$ at the first sampling date. † Last sampling date not included in regression analysis. ‡ Last 2 sampling dates not included in regression analysis. § 64,550 and 129,107 plants/ha, respectively.

in Table 4. In Fig. 1 and 4 the curves after N_0 represent equation [2]. The solid lines before the peak were merely fitted to the points. The dashed lines represent the estimated increase in NO_3-N in the petioles. The increase in NO_3-N can be attributed to an increase in N available to the plant as a result of an expanding root system and nitrification as soil temperature increases.

In Fig. 1 N_0 is the NO_3-N on July 8, and C was determined by the change in NO_3-N between July 8 and July 22. In Fig. 4 the date of the first N_0 is the NO_3-N concentration on June 29, except on the M_2-224 treatment where N_0 was on July 6. C was determined by the change in NO_3-N concentration between June 29 and July 13, except on the M_2-224 treatment, where C was determined by the change between July 6 and July 13. For the second evaluation N_0 is the NO_3-N concentration on July 20, and C was determined by the change in NO_3-N concentration between July 20 and July 27. The regression equation based on all sampling dates after N_0 are plotted in Fig. 2 and 3.

Use of equation [2] within a given season requires that the first petiole analysis used for prediction be obtained after the peak NO_3-N concentration has occurred. The peak concentration had not been reached on the M_1-224 N and M_2-224 N treatments on June 29 (Fig. 3, 4), so the next sampling date of July 6 was used for the peak NO_3-N concentration. This delay was probably caused by the side-dressed N not being completely available to the root system.

There was a distinct increase in the NO_3-N in the petioles on the July 20 sampling date in 1967 above its predicted value (Fig. 3, 4). This increase in NO_3-N content may have been caused by light rains received on July 17 and 19 moving nitrates that had accumulated in the ridges into the root zone and increasing the NO_3-N level in the petioles, or by an additional N supply being reached by the roots in the lower soil layers. In addition root growth into the ridges high in NO_3-N would be promoted by the surface soil remaining wet for several days due to the heavy plant canopy cover and the reduced solar radiation on July 14 and 16, and to a lesser extent on

July 17 and 18. Also, the July 20 sampling date was on the day before an irrigation. All of these factors may have contributed to the higher concentration of NO_3-N on July 20.

Equation [2] also represents petiole data obtained at other locations (Fig. 6). Regardless of the location, difference in climate and soil or the technique used in taking and analyzing the samples, the change in NO_3-N in the beet petioles is represented by this equation with a reasonable degree of accuracy (Table 4). The data presented indicate that changes in the NO_3-N concentration in the sugarbeet petioles for all practical purposes can be predicted unless there is a change in supply such as occurred near July 20, 1967. Therefore, if NO_3-N concentration in the petioles can be determined on two dates after the peak value has been reached, the NO_3-N concentration during the remainder of the season can be predicted to determine the adequacy of available N. An alternate procedure can be used if the C values are similar for a given soil, previous cropping history, and climatic region. In this case, only one sampling would be required and an average C value used.

Use of equation [2] for predicting the adequacy of N requires an accurate method of determining the NO_3-N in plant tissue. A quick-test on the fresh tissue as normally used by commercial companies was compared with a more detailed laboratory analysis used in this study. The quick-test has arbitrary units ranging from 0 to 150. The standard error of the quick-test measurements was 16.4 for the 1966 season ($r = 0.82$), and 18.9 for the 1967 season ($r = 0.80$). Variations in the slope and intercept of the regression of the quick-test data on the laboratory data occurred on the different dates of sampling. This variation could have resulted from differences in the petiole tissue or in the sampling technique used for the quick-test. Variations using a quick-test method may be too great to be used to predict N needs with equations [2], [3a] and [3b] unless a larger number of subsamples are used and the interval between sampling dates for determining C is increased. Also, if the sample from the first date were frozen and a direct comparative test used when the second sample is taken, greater accuracy might be possible.

Other factors must be considered before recommending N on the basis of a tissue test. When N fertilizer is mixed in the upper soil layers or side-dressed followed by adequate irrigation for distributing the fertilizer throughout the root zone, a functional relationship based on the NO_3-N concentration of the petioles early in the season for predicting N needs is possible. If the beets had been side-dressed and the root system was not utilizing this N for lack of water or other reasons, the NO_3-N content of the petioles might not reflect the soil and fertilizer N that could become available later in the season. Also, if heavy rainfall occurred during the season, NO_3-N accumulated in the ridges would be washed into the root zone, causing a subsequent increase in the NO_3-N levels in the petioles.

Petiole analyses, if properly used, can be a valuable guide in recommending N fertilizer for sugarbeets. The disadvantage to the use of any tissue test is that the results are obtained at such a time that the application of N to the crop could be of questionable value. A soil test for available N, performed early in the season, would be preferred to a tissue test so that fertilizer could be applied before planting or side-dressed early in the growing season. However, determining the optimum N fertility level by soil test does not reflect irrigation practices in which leaching may be in-

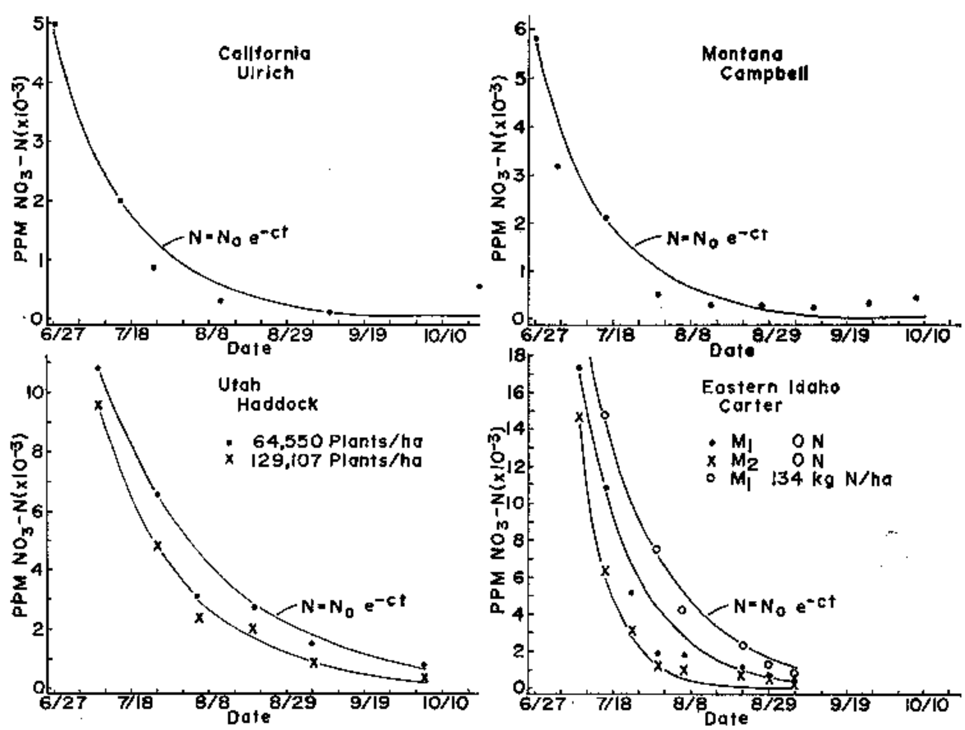

Fig. 6. NO_3-N concentration in sugarbeet petioles at various sampling dates and locations. Ulrich (7), Campbell (1), Haddock (4), and Carter (unpublished).

volved. Tissue testing can be used to supplement a soil test in predicting the adequacy of N. The use of the time-dependent, theoretical approach discussed in this paper for predicting N needs should allow for better control in adding supplemental N for sugarbeets and be used to characterize the N status of soil-crop systems.

LITERATURE CITED

1. Campbell, R. E., and F. G. Viets, Jr. 1967. Yield and sugar production by sugar beets as affected by leaf area variations induced by stand density and nitrogen fertilization. Agron. J. 59:349-354.
2. Carter, J. N., O. L. Bennett, and R. W. Pearson, 1967. Recovery of fertilizer nitrogen under field conditions using nitrogen-15. Soil Sci. Soc. Amer. Proc. 31:50-56.
3. Hach Chemical Company, Ames, Iowa. 1966. Water and sewage analysis procedures. Catalog No. 9:29.
4. Haddock, Jay L. 1953. Sugar beet yield and quality as affected by plant population, soil moisture condition and fertilization. Utah Agr. Sta. Bull. 362.
5. Johnson, C. M., and A. Ulrich. 1959. Analytical methods for use in plant analysis. Calif. Agr. Exp. Sta. Bull. 766.
6. Ulrich, A. 1950. Critical nitrate levels of sugar beets estimated from analysis of petioles and blades, with special reference to yields and sucrose concentrations. Soil Sci. 69:291-309.
7. ———, D. Ririe, F. J. Hills, A. G. George, and M. D. Morse. 1959. Plant analysis, a guide for sugar beet fertilization. Calif. Agr. Exp. Sta. Bull. 766.